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Abundance and Potential Biological Removal (PBR) Estimates for Canada's High Arctic Atlantic Walrus (*Odobenus rosmarus rosmarus*) Management Stocks, Summer 2022

C.J.D. Matthews, S.-T. Zhao, B.A.H. Sherbo, B.A. Biddlecombe,
M. Ghazal, and C.A. Hornby

Fisheries and Oceans Canada
Freshwater Institute
501 University Crescent
Winnipeg, MB R3T 2N6

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Coastal photographic aerial surveys of the High Arctic Atlantic walrus (*Odobenus rosmarus rosmarus*) population were conducted during the latter half of August 2022. Counts of walruses hauled out at terrestrial sites and on ice were used to estimate abundances of the three High Arctic walrus management stocks: Penny Strait-Lancaster Sound (PS-LS), West Jones Sound (WJS), and Baffin Bay (BB). Two fixed-wing aircraft (Twin Otter) flew simultaneously along coastlines encompassing the summer ranges of the PS-LS and WJS stocks and summer core-use areas of the BB stock. Two independent surveys of both the PS-LS and WJS stocks were completed, and three surveys of the BB stock were completed. Total haulout counts (including walruses on sea ice) for the PS-LS stock were 266 and 495 (August 13-16 and 24-27), 347 and 656 for the WJS stock (August 17-18 and August 22), and 254, 3, and 6 for the BB stock (August 7, 16, and 26). Adjusting counts for availability bias using a previously published mean proportion of hauled out animals (p = 0.3) produced abundance estimates of 887 (95% confidence interval [CI] = 475–1,653) and 1,650 (95% CI = 696–3,909) for the PS-LS stock; 1,157 (95% CI = 618–2,166) and 2,187 (95% CI = 1,132–4,224) for the WJS stock, and 847 (95% CI = 254*–3,286), 10 (95% CI = 3*–44), and 20 (95% CI = 6*–83) for the BB stock. Higher counts for the PS-LS and WJS stocks during their second respective surveys may reflect transitioning of walruses from melting sea ice onto terrestrial haulouts or possibly an influx of walruses from the BB stock, for which counts were negligible over the same period. Using a distance/time criterion of 45 km/day, BB walrus could not have crossed into adjacent stock boundaries ~ 600-1,000 km away between August 7 and the first PS-LS and WJS surveys (August 13-18), but could possibly have covered those distances in the period leading up to the second surveys from August 22-27. Fuel closures also prevented some coastal areas of Ellesmere Island from being surveyed, introducing potential negative bias in BB stock counts. Potential Biological Removal (PBR) estimates were based on abundance estimates from the first surveys of each stock due to uncertainty regarding walrus movements among stocks during subsequent surveys, equaling 7 walruses for the PS-LS stock, 9 walruses for the WJS stock, and 5 walruses for the BB stock.

* actual count, which exceeds the estimated lower 95% confidence limit (CL).

INTRODUCTION

Atlantic walrus (*Odobenus rosmarus rosmarus*) occur as two genetically distinct populations in the eastern Canadian Arctic: the High Arctic population and the central Arctic population (Shafer et al. 2014). The High Arctic population is distributed across Baffin Bay and the eastern waterways of the Canadian Arctic Archipelago. For management purposes (in Canada), the High Arctic population is currently subdivided into three stocks based on genetic or distribution differences inferred from telemetry and tissue microchemistry (NAMMCO 2006, NAMMCO 2011, Stewart 2008): the Penny Strait-Lancaster Sound (PS-LS) stock, the West Jones Sound (WJS) stock, and the Baffin Bay (BB) stock, which is shared with Greenland (Figure 1). Walruses from all three stocks are hunted by Inuit in Canada for food and other products such as ivory (Matthews et al. 2018), while walruses from the BB stock are also hunted in the Qaanaaq area of West Greenland, where they are distributed from fall through spring (Figure 1).

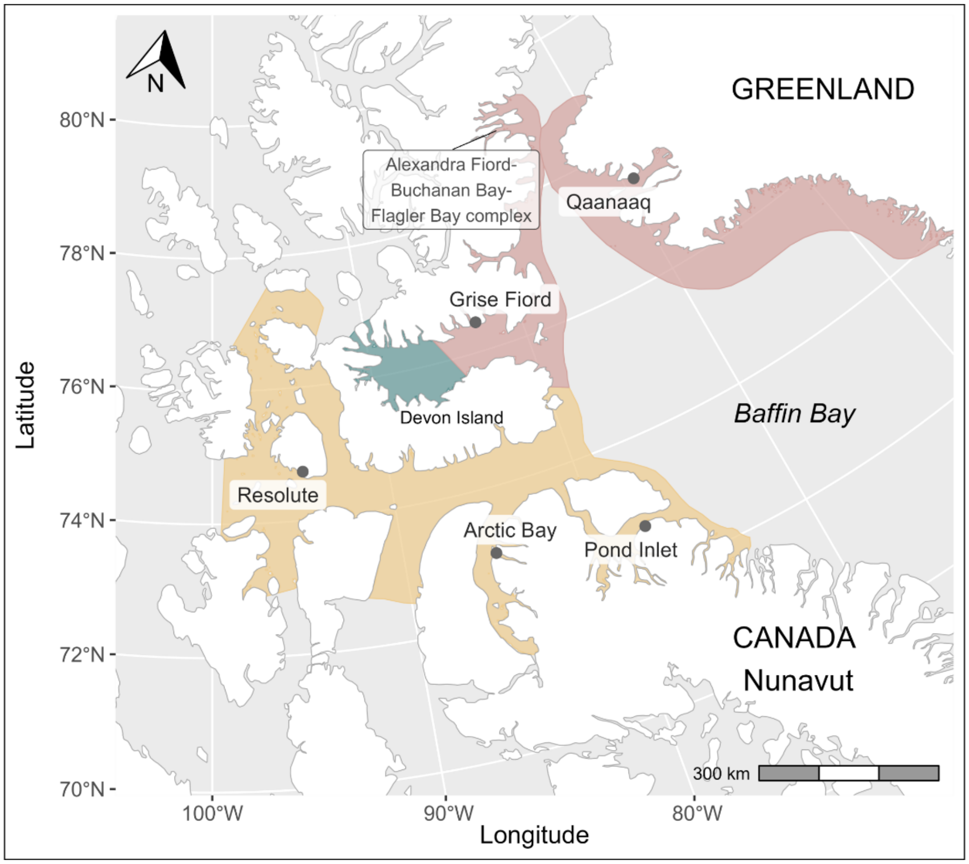

Figure 1. Ranges of the High Arctic Atlantic walrus management stocks in the eastern Canadian Arctic. The 2022 coastal survey covered the summer ranges of the Penny Strait-Lancaster Sound (PS-LS; yellow) and West Jones Sound (WJS; blue), and summer core-use areas (i.e., Alexandra Fiord/Buchanan Bay/Flagler Bay complex) of Baffin Bay (BB; pink) stocks (see also Figures 3-5).

Fisheries and Oceans Canada (DFO) conducts regular population assessments of exploited marine mammal stocks to determine abundance and sustainable harvest levels. DFO's last assessment of all three High Arctic walrus stocks were based on aerial surveys conducted in 2009, which produced abundance estimates of 727 (623–831) walruses in the PS-LS stock, 470 (95% confidence limit [CL] 297–1,732) walruses in the WJS stock, and 1,251 (571–2,477) walruses in the BB stock (Stewart et al. 2014a,c). To update these estimates, a new coastal photographic aerial survey of all three stocks was conducted during the latter half of August 2022. Our understanding of walrus distribution and movement patterns in the region has changed over the past decade, with walruses tagged in Smith Sound crossing the putative boundaries of all three stocks during the open-water season (Heide-Jørgensen et al. 2017). Two aircraft were therefore used to survey the three stocks in as short a period as possible to avoid biased counts due to potential directed movements among stocks.

Following well-established 'colony count' methods for estimating pinniped population sizes (Stenson et al. 2003, Lydersen et al. 2008, Stenson et al. 2010), the survey covered known terrestrial haulout sites and adjoining coastline. Counts of walruses hauled out on land (and ice, when observed) were adjusted for availability bias to estimate stock abundance and Potential Biological Removal (PBR). Secondary objectives included updating terrestrial walrus haulout locations to inform the management plan and zoning framework of the Tallurutiup Imanga National Marine Conservation Area (NMCA), the spatial extent of which encompasses the PS-LS and BB stock ranges.

MATERIALS AND METHODS

SURVEY AREA AND PROTOCOL

Survey coverage and timing were based on previous surveys (Stewart et al. 2014a,c) and Inuit Qaujimajatuqangit of terrestrial walrus haulout locations. Individual stock surveys were conducted from August 7-27, 2022, when sea ice is typically at a seasonal minimum and maximum numbers of PS-LS and WJS walruses occur at terrestrial haulout sites. Persistent drifting pack ice along the east coast of Ellesmere Island throughout summer allows walruses from the BB stock to continue to haul out on ice. The coastal surveys of Ellesmere, Devon, Cornwallis, and Bathurst Islands encompassed almost all previously identified terrestrial High Arctic walrus haulout sites, regardless of current status (Figure 2). One haulout site on the south coast of Lancaster Sound (Table 1, Figure 2 - #30) that has been abandoned for decades (Stewart et al. 2014c) was not included in the survey, as well a single haulout site on Coburg Island due to airspace restrictions (also considered abandoned; Table 1, Figure 2 - #47) and the one right next to it at the base of Jakeman Glacier (Table 1, Figure 2 - #50). Four haulout sites on the Greenland coast of Smith Sound that have been abandoned since the early 1900s (Heide-Jørgensen et al. 2017) were also not included in the survey (Table 1, Figure 2 - #54-57). Adjacent coastline between haulout sites, including islands, was also surveyed, particularly as reductions in High Arctic sea ice (Mudryk et al. 2018) may have driven walruses to haul out at new terrestrial sites. When constrained by time, direct flights between adjacent haulout sites were prioritized over coastlines to ensure survey completion. Newly observed terrestrial haulout sites were included in follow-up surveys.

Two De Havilland Twin Otter DHC-6 aircraft were flown simultaneously at a target altitude of 1,000 feet (305 m) and a speed of 100 knots (185 km/h). Each aircraft was fitted with two rear bubble windows and a ventral camera port that allowed the land/water surface directly below the aircraft to be photographed. Two Nikon D850 cameras fitted with either a 35 mm or 55 mm Zeiss lens were mounted vertically, pointing straight down through the port, with their widths perpendicular to the flight path. Images were taken at 3-second intervals, resulting in an image footprint of 313 x 209 m with an approximate 25% overlap between consecutive photos using the 35 mm lens and a 200 x 133 m footprint and < 10% overlap using the 55 mm lens. Two observers seated at bubble windows relayed walrus sightings to a camera operator, who recorded the time and photograph corresponding to each sighting. The flightpath was continually adjusted to keep the coastline in the cameras' fields of view, and aircraft position and altitude were recorded every second using a Garmin GPS (Bad Elf) and Bluetooth module accessory (Foolography Unleashed D200+ Bluetooth Module), allowing geo-referenced images to be saved directly to the laptop hard drive. It was not uncommon for the survey aircraft to disturb walruses hauled out on land or ice, causing them to enter the water. When this occurred, the aircraft circled back over the haulout site a second time in an effort to obtain better images for counting individual walruses.

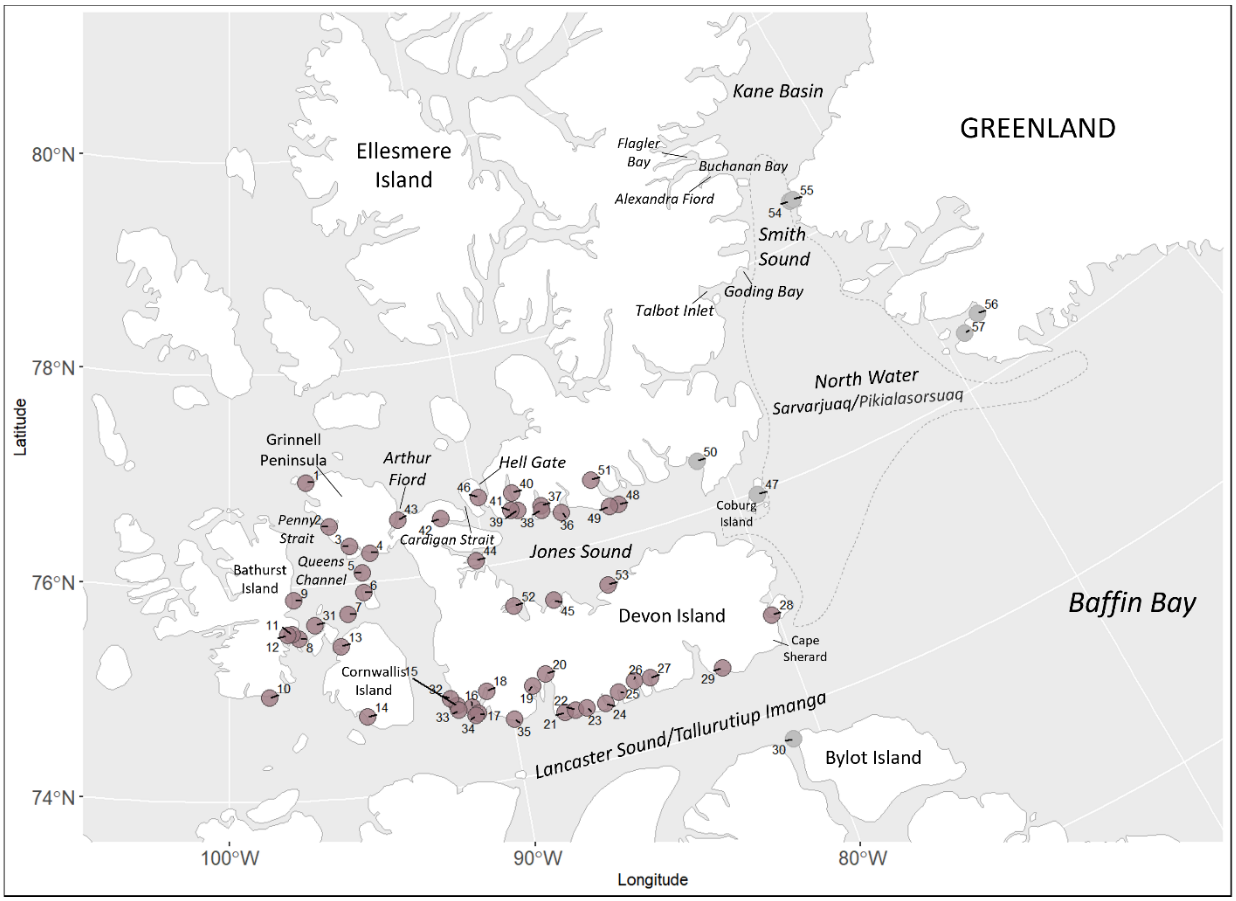

Figure 2. Terrestrial haulout sites surveyed in August 2022 to estimate abundances of the three management stocks of the High Arctic walrus population in Canada. Seven of the 57 haulouts were not included in the survey (# 30, 47, 50, 54-57; shaded grey), primarily because they are considered abandoned (see also Table 1). A notional North Water polynya boundary (dashed grey line) is shown, representing the May monthly mean extent (Hornby et al. 2021).

Table 1. Known terrestrial haulout sites surveyed in August 2022 to estimate abundances of the three management stocks (Penny Strait-Lancaster Sound [PS-LS], West Jones Sound [WJS], and Baffin Bay [BB]) of the High Arctic Atlantic walrus population in Canada. Seven haulouts not surveyed, primarily because they are considered abandoned, are shaded grey (see also Figure 2). Newly observed haulouts during the 2022 survey are presented in Tables 2-4 and Figures 3-5. ID corresponds to Figure 2 haulout locations.

ID	Stock	Haulout Site Name	Latitude	Longitude	Status
1	PS-LS	Village Bay	76.9747	-96.8175	Active
2	PS-LS	Barrow Harbour	76.5483	-95.9792	Active
3	PS-LS	Inglis Bay	76.3489	-95.2231	Active
4	PS-LS	Cape Hornby	76.2742	-94.4635	Active
5	PS-LS	Margaret Island	76.0912	-94.8164	Active
6	PS-LS	Baillie Hamilton Island	75.9101	-94.8473	Active
7	PS-LS	Houston-Stewart Island	75.7204	-95.5026	Active
8	PS-LS	Brooman Point	75.5167	-97.4000	Active
9	PS-LS	Rapid Point	75.8740	-97.5442	Uncertain
10	PS-LS	Moore Island	74.9723	-98.5652	Uncertain
11	PS-LS	Markham Point	75.5585	-97.6651	Active
12	PS-LS	Markham West	75.5533	-97.8382	Active
13	PS-LS	Marshall Penn	75.4215	-95.8565	Active
14	PS-LS	Allen Bay	74.7449	-95.1111	Abandoned
15	PS-LS	Union Bay	74.7554	-91.8807	Uncertain
16	PS-LS	Gascoyne Inlet	74.7210	-91.3646	Active
17	PS-LS	Radstock Bay	74.6592	-91.1753	Active
18	PS-LS	Kearney Cove	74.8526	-90.7825	Active
19	PS-LS	Custance Inlet	74.8228	-89.1172	Active
20	PS-LS	Ryder Inlet	74.9074	-88.5860	Active
21	PS-LS	Graham Inlet	74.5189	-88.1819	Active
22	PS-LS	No Name Bay	74.5205	-87.8093	Active
23	PS-LS	Blanley Bay	74.5216	-87.3997	Active
24	PS-LS	Stratton Inlet	74.5192	-86.7324	Uncertain
25	PS-LS	Burnett Inlet	74.5950	-86.1951	Active
26	PS-LS	Powell Inlet	74.6602	-85.5711	Active
27	PS-LS	Cuming Inlet	74.6504	-85.0066	Active
28	PS-LS	Philpots Island	74.8720	-80.1974	Abandoned
29	PS-LS	Dundas Harbour	74.5476	-82.4626	Abandoned

ID	Stock	Haulout Site Name	Latitude	Longitude	Status
30	PS-LS	Wollaston Island	73.7167	-80.9167	Abandoned
31	PS-LS	Milne Island	75.6362	-96.7802	Uncertain
32	PS-LS	Innes Point	74.8282	-92.0915	Uncertain
33	PS-LS	Beechey Island	74.7114	-91.8485	Abandoned
34	PS-LS	Cape Ricketts	74.6415	-91.2887	Uncertain
35	PS-LS	Cape Hurd	74.5519	-89.9695	Uncertain
36	WJS	Baad Fiord	76.3564	-86.6947	Active
37	WJS	Musk Ox Fiord - spit	76.4590	-87.4324	Active
38	WJS	Musk Ox Fiord – west	76.4147	-87.4586	Active
39	WJS	Clement Uglit	76.4662	-88.3980	Active
40	WJS	Borgen Mount	76.6314	-88.4760	Active
41	WJS	Walrus Fiord	76.4718	-88.6460	Active
42	WJS	Norfolk Island	76.5113	-91.4965	Active
43	WJS	Arthur Fiord	76.5527	-93.2043	Active
44	WJS	West Fiord	76.0698	-90.3748	Active
45	WJS	Nookap/Saukuse Island	75.5712	-87.7500	Uncertain
46	WJS	Blubber Point	76.6500	-89.8333	Abandoned
47	WJS	Coburg Island	75.9760	-79.1401	Abandoned
48	WJS	South Cape	76.2934	-84.4428	Uncertain
49	WJS	West of South Cape	76.2955	-84.8123	Uncertain
50	WJS	Jakeman Glacier (base)	76.4643	-80.9485	Uncertain
51	WJS	Sannialuit ("place with bones")	76.5833	-85.2500	Uncertain
52	WJS	Thomas Lee Inlet	75.5885	-89.2434	Uncertain
53	WJS	Cape Newman Smith	75.5943	-85.6310	Uncertain
54	BB	Littleton Island	78.3696	-72.8654	Abandoned
55	BB	Coast opposite Littleton Island	78.3705	-72.7049	Abandoned
56	BB	Uvdle-1	76.5847	-68.1802	Abandoned
57	BB	Uvdle-2	76.4872	-69.0370	Abandoned

PHOTO ANALYSIS

Photographs of PS-LS and WJS stock surveys were analysed by two readers who each independently counted walruses in all photographs with recorded sightings. Each photograph was opened in QGIS (v. 3.14, QGIS.org 2020) and adjusted for brightness and/or contrast to improve readability. When available, both the 35 and 55 mm photographs of each haulout were counted in random order. Spatial points were superimposed on the head or body of each walrus and saved as a shape file that was referenced to the respective photo. Walruses that had been clearly hauled out on land or ice but were startled into the water by the survey aircraft, which was usually evident from trails of disturbed sediment and/or feces, were included in the haulout count. Given that availability bias adjustments were based on wet/dry readings from previous satellite telemetry studies (see below), walruses in shallow water whose backs were clearly out of the water and dry were also included in counts. Regression analysis (R v. 4.0.5; R Core Team 2021) of counts by Reader 2 on counts by Reader 1 showed essentially no inter-observer variation for either 35 mm or 55 mm photographs, with intercept estimates (35 mm = 0.096 ± 0.68; 55 mm = 0.92 ± 0.70) that did not differ from 0 ($p > 0.2$), and slope estimates (35 mm = 0.983 ± 0.01; 55 mm = 0.993 ± 0.01) that did not differ from 1 ($p > 0.1$). After a period of several weeks, photos and associated shapefiles for which counts differed were re-examined by the two original readers together to agree on a consensus count. Counts from 55 mm photographs were considered more accurate, given the slightly better correlation between readers, and were preferred over 35 mm images for abundance estimation when available.

Walruses observed during surveys of the Alexandra Fiord/Buchanan Bay/Flagler Bay complex (considered a summer core-use area of the BB stock) were typically in smaller numbers on ice (or in water) and distributed across each photograph, therefore making them more likely to have been missed by survey observers than the relatively large walrus aggregations at terrestrial PS-LS and WJS haulouts. Therefore, each of the approximately 12,500 photos taken during the three BB stock surveys was manually read by a new single, third reader. All observed walruses, including those in water, were counted, but abundance estimates were based only on walruses hauled out on land and ice (see above). Duplicate counts of walruses that appeared in overlapping portions of adjacent photos, which were easy to identify due to the small numbers of observed walruses and the ease with which adjacent photos could be aligned using features like drifting ice, were excluded from total counts.

COUNT ANALYSIS – ABUNDANCE ESTIMATION

Absolute abundance estimates based on walrus haulout counts must take into account availability bias, which is the proportion of the total population that was not hauled out during the survey and therefore not counted. Moreover, the tendency for walrus haulout behavior to be synchronized in response to weather conditions or social factors (Salter 1979, Lydersen et al. 2008, Born and Knutsen 1997, Udevitz et al. 2009) causes considerable temporal variation in haulout numbers that must be properly captured by variance estimates (Stewart et al. 2014c, Doniol-Valcroze et al. 2016). By comparison, detection or perception bias – animals available to be counted but missed by observers – is assumed to be negligible in photographs that allow for thorough, repeated searches of target animals (Stewart et al. 2014c).

Using models of virtual populations of known-size that mimicked the overdispersion of counts due to correlated walrus haulout behavior, Doniol-Valcroze et al. (2016) concluded the simple count method, which is the number of hauled out animals at a given site (or an average of multiple independent counts), adjusted by the average proportion of time hauled-out provides a reliable and unbiased estimator of walrus abundance. Following Doniol-Valcroze et al. (2016) and several other walrus stock assessments since then (Mosnier et al. 2023, Sauvé et al. 2024), we estimated the abundance of each stock ($\widehat{N}$) by first estimating the abundance of walruses at each haulout site ($\widehat{N}_i$) within the purported stock range by dividing each haulout count (C_i) by the estimated proportion of the population hauled out (P):

$$\widehat{N}_i = \frac{C_i}{P}$$

where P = 0.30, the average of published walrus haulout proportions during summer/fall (Hammill et al. 2016b). We note that this proportion includes walruses hauled out on land and/or ice and should, therefore, be appropriate for application to counts of walruses on both substrates. Unfortunately, the two closest Nunavut communities to the survey either did not support (Grise Fiord, NU) or respond to (Resolute Bay, NU) plans to satellite tag walruses, which would have allowed us to use concurrent telemetry data to derive survey-specific haulout proportions.

Variance was calculated following the Doniol-Valcroze et al. (2016) formula that accounts for the relationship between counts and walrus haulout behavior. Considering k is the number of counts per haulout (which equalled 1 in all cases; no averages were used because no single haulout site had more than one independent flyover per survey), then:

$$var(\widehat{N}_i) \approx \widehat{N}_i \times \frac{1-P}{k\,P} \times \sigma^2 + \frac{\widehat{N}_i^{\,2}}{P^2} \times var(P)$$

where $var(P)$ = 0.000469 (Sauvé et al. 2024), and σ^2 (the overdispersion factor) is equal to:

$$\sigma^2 = 1 + (\widehat{N}_i - 1) \times rho$$

with rho being the correlation factor among walruses. Attempts to quantify correlation in haulout behavior of the surveyed stocks using automated stationary cameras at four haulout sites were unsuccessful, as most cameras were destroyed by polar bears shortly after deployment. We therefore used Mosnier et al. (2023) estimate of 0.26 (95% confidence interval [CI] = 0.140-0.362) based on the Bayesian model framework developed by Doniol-Valcroze et al. (2016) and daily counts of walrus hauled out on Walrus Island, NU, during August 1976 and 1977 (Mansfield and St. Aubin 1991).

Stock abundance ($\widehat{N}$) was calculated by summing the independent estimates for individual haulout sites within each respective stock for each survey. To minimize bias (i.e., double counting) due to potential directed walrus movements among haulout sites, we used a distance/time criterion of 45 km/day, calculated from telemetry data of walruses migrating across Davis Strait (Dietz et al. 2014), as a cut-off for assessing independence of haulout counts (Stewart et al. 2014b, Hammill et al. 2016b).

Confidence limits (95%) around each stock abundance estimate were calculated assuming a log-normal distribution with a mean given by the sum of the haulout size estimates ($\widehat{N}_i$) and variance given by the sum of the variances of the haulout size estimates ($var(\widehat{N}_i)$). In cases where the lower confidence limit (CL) was less than the actual count, which occurred for all three surveys of the BB stock, the lower confidence limit was replaced by the count value.

POTENTIAL BIOLOGICAL REMOVAL (PBR) ESTIMATION

Potential Biological Removal (PBR), defined as the maximum number of animals that can be removed from a stock, excluding natural mortality, while allowing it to attain or maintain its optimal sustainable size (Wade 1998), is DFO's default method to estimate sustainable removal levels for 'data-poor' stocks (Stenson et al. 2012, Mosnier et al. 2023, Sauvé et al. 2024). PBR is calculated as:

$$PBR = 0.5 \times R_{max} \times F_R \times N_{min}$$

where R_{max} is the maximum rate of population increase, and was set to 8% (Witting and Born 2014) for consistency with previous DFO walrus stock assessments (Hammill et al. 2016a,b, Hammill et al. 2023, Sauvé et al. 2024); F_R is a recovery factor that can vary from 0.1 to 1, and was set at 0.25 in accordance with DFO guidelines for stocks whose abundance with respect to carrying capacity/historical size and growth trend are unknown (DFO 2025); and N_{min} is the estimated population size using the approximate 20-percentile of the log-normal distribution of $\widehat{N}$, calculated as:

$$N_{min} = \frac{\widehat{N}}{e^{\left\{0.842\left(\ln(1+\ CV^2)\right)^{0.5}\right\}}}$$

where CV is the coefficient of variation for $\widehat{N}$. Because the possibility of directed movements of walrus from the BB stock southward across the purported boundaries of the PS-LS and WJS stocks between surveys could not be independently evaluated (see Results and Discussion), PBR estimates were based on the first surveys of each management stock.

RESULTS

All known terrestrial haulouts of both the WJS and PS-LS stocks were surveyed twice (Figures 3 and 4). The first surveys of the PS-LS and WJS stocks during August 13-16 and August 17-18, respectively, covered all haulouts and intervening coastline (Figures 3 and 4). During the second surveys (August 24-27 and August 22, respectively), haulout sites were prioritized and covered in a more direct manner to manage time constraints during the final week of August when just one plane was available. Overall, walruses were observed at 10 of the 53 known PS-LS and WJS terrestrial haulout sites (Figures 3 and 4, Tables 2 and 3), and at another nine that were previously unreported (Tables 2 and 3). The Alexandra Fiord/Buchanan Bay/Flagler Bay complex of the Baffin Bay (BB) stock was surveyed three times, on August 7, 16, and 26 (Figure 5), although planned coverage of potential walrus range outside of this area was not possible due to distance limits imposed by fuel closures. Notably, a relatively large number of walruses were observed at a new terrestrial haulout on a small island in Alexandra Fiord on August 7 (Table 4, Figure 5). Including opportunistic flyovers in early August prior to the surveys, time series comprising two to four counts were obtained for 14 haulout sites (Figure A1). Opportunistic counts did not contribute to abundance estimates but were considered in a qualitative assessment of temporal variation in walrus numbers across the survey period (see Discussion).

The second survey of the WJS and all three surveys of the BB stock were completed within several hours on the same day. Haulouts surveyed over two (WJS first survey) or three days (both PS-LS surveys) were more than 90 and 135 km apart, respectively. Therefore, no counts exceeded our distance/time cut-off, and all were therefore included in stock abundance estimates. Forty-five walruses observed at the tip of Grinnell Peninsula (haulout site NEW8; Figure 4, Table 3) fell outside the purported summer ranges of both the PS-LS and WJS stocks (Figure 1). Observations of walrus in Arthur Fiord during summer (Davis et al. 1978) suggest they swim westward through Hell Gate or Cardigan Strait, so we included the 45 Grinnell Peninsula walruses in the first total WJS stock count, similar to Stewart et al.'s (2014c) treatment of 20 walruses observed in Arthur Fiord in 2004.

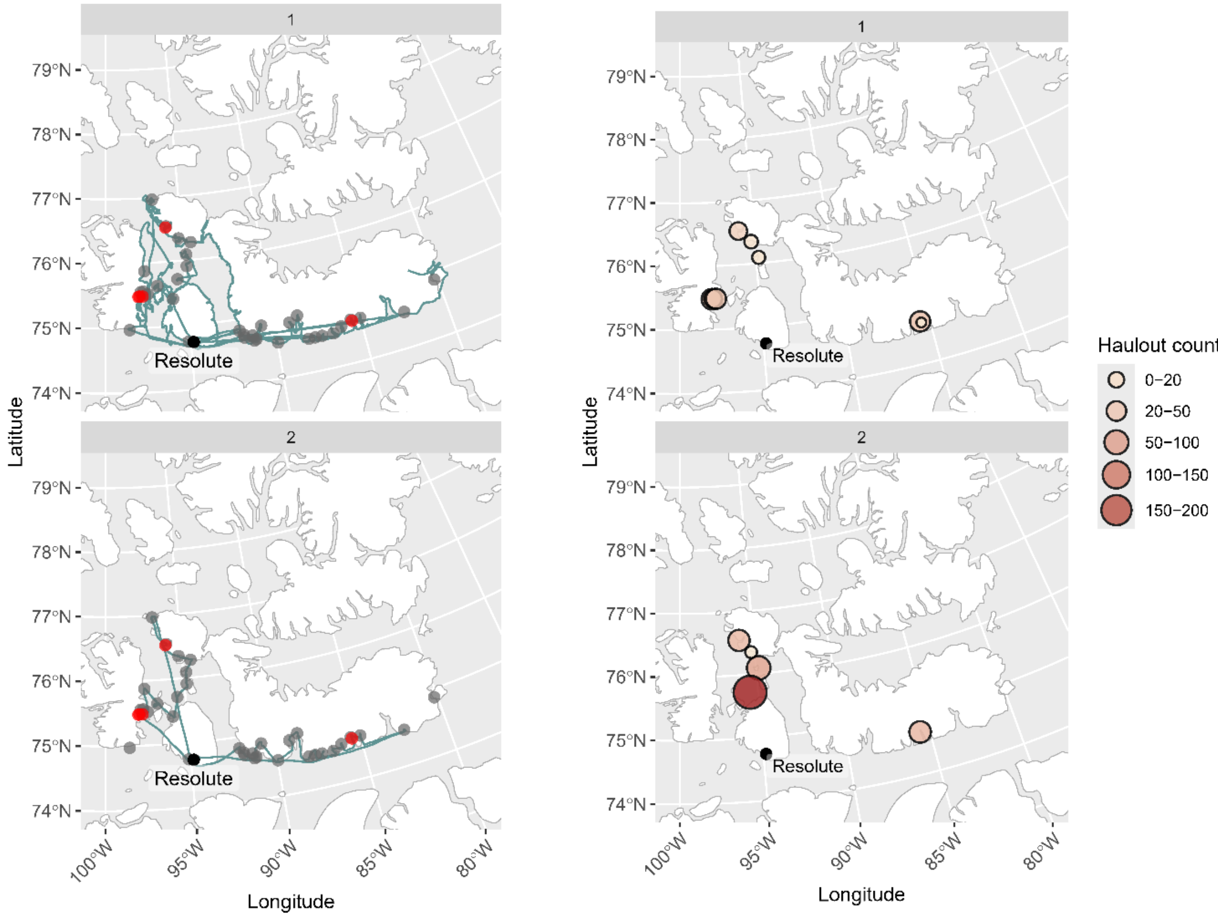

Figure 3. Flight tracks (blue lines) and terrestrial haulouts surveyed (grey points), including three newly identified ones (red points), during the first (August 13 and 16; top left) and second (August 24 and 27; bottom left) surveys of the Penny Strait-Lancaster Sound (PS-LS) walrus management stock. The right panels (top and bottom) indicate the raw counts at haulouts where walrus were observed on each survey.

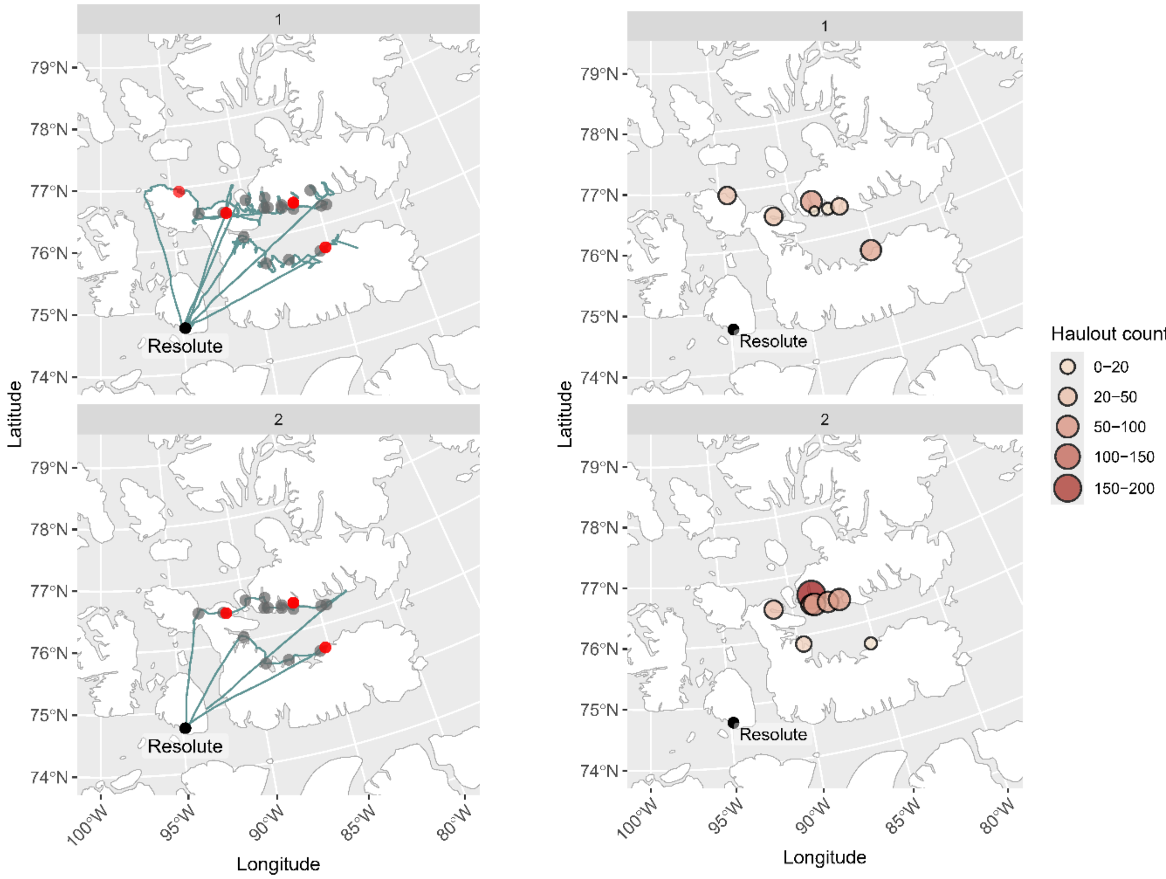

Figure 4. Flight tracks (blue lines) and terrestrial haulouts surveyed (grey points), including four newly identified ones (red points), during the first (August 17 and 18; top left) and second (August 22; bottom left) surveys of the West Jones Sound (WJS) walrus management stock. The right panels (top and bottom) indicate raw counts at haulouts where walrus were observed on each survey.

Table 2. Counts of walruses at terrestrial haulout sites and on ice during surveys of the Penny Strait-Lancaster Sound (PS-LS) stock during August 2022. Counts on land and ice contributed to total abundance estimates. Sites shaded grey were not surveyed. ID corresponds to Figure 2 haulout locations.

ID	Stock	Haulout Site	Count (Survey 1)	Count (Survey 2)
1	PS-LS	Village Bay	0	0
2	PS-LS	Barrow Harbour	0	67
3	PS-LS	Inglis Bay	11	6
4	PS-LS	Cape Hornby	0	0
5	PS-LS	Margaret Island	9	93
6	PS-LS	Baillie Hamilton Island	0	0
7	PS-LS	Houston-Stewart Island	0	259
8	PS-LS	Brooman Point	0	0
9	PS-LS	Rapid Point	0	0
10	PS-LS	Moore Island	0	0
11	PS-LS	Markham Point	0	0
12	PS-LS	Markham West	0	0
13	PS-LS	Marshall Penn	0	0
14	PS-LS	Allen Bay	0	0
15	PS-LS	Union Bay	0	0
16	PS-LS	Gascoyne Inlet	0	0
17	PS-LS	Radstock Bay	0	0
18	PS-LS	Kearney Cove	0	0
19	PS-LS	Custance Inlet	0	0
20	PS-LS	Ryder Inlet	0	0
21	PS-LS	Graham Inlet	0	0
22	PS-LS	No Name Bay	0	0
23	PS-LS	Blanley Bay	0	0
24	PS-LS	Stratton Inlet	0	0
25	PS-LS	Burnett Inlet	0	0
26	PS-LS	Powell Inlet	56	70
27	PS-LS	Cuming Inlet	0	0
28	PS-LS	Philpots Island	0	0
29	PS-LS	Dundas Harbour	0	0
30	PS-LS	Wollaston Island	-	-

ID	Stock	Haulout Site	Count (Survey 1)	Count (Survey 2)
31	PS-LS	Milne Island	0	0
32	PS-LS	Innes Point	0	0
33	PS-LS	Beechey Island	0	0
34	PS-LS	Cape Ricketts	0	0
35	PS-LS	Cape Hurd	0	0
-	PS-LS	NEW3 (76.53038 N, 96.02681 W)	33	0
-	PS-LS	NEW4 (75.47944 N, 97.98206 W)	59	0
-	PS-LS	NEW5 (75.48642 N, 97.91464 W)	33	0
-	PS-LS	NEW6 (75.48338 N, 97.72328 W)	55	0
-	PS-LS	NEW7 (74.63935 N, 85.51896 W)	4	0
-	PS-LS	ICE	6	n/a
		PS-LS TOTALS	**266**	**495**

Table 3. Counts of walruses at terrestrial haulout sites and on ice during surveys of the West Jones Sound (WJS) stock during August 2022. Counts on land and ice contributed to total abundance estimates. Sites shaded grey were not surveyed. ID corresponds to Figure 2 haulout locations.

ID	Stock	Haulout Site	Count (Survey 1)	Count (Survey 2)
36	WJS	Baad Fiord	0	0
37	WJS	Musk Ox Fiord - spit	7	82
38	WJS	Musk Ox Fiord – west	0	0
39	WJS	Clement Uglit	3	102
40	WJS	Borgen Mount	90	222
41	WJS	Walrus Fiord	0	67
42	WJS	Norfolk Island	0	0
43	WJS	Arthur Fiord	0	0
44	WJS	West Fiord	0	0
45	WJS	Nookap/Saukuse Island	0	0
46	WJS	Blubber Point	0	0
47	WJS	Coburg Island	-	-
48	WJS	South Cape	0	0
49	WJS	West of South Cape	0	0
50	WJS	Jakeman Glacier (base)	-	-
51	WJS	Sannialuit ("place with bones")	0	0
52	WJS	Thomas Lee Inlet	0	0

ID	Stock	Haulout Site	Count (Survey 1)	Count (Survey 2)
53	WJS	Cape Newman Smith	0	0
-	WJS	Sandhook Bay	0	27
-	WJS	NEW2 (76.45370 N, 86.61022 W)	36	94
-	WJS	NEW8 (76.93526 N, 94.41305 W)	45	0
-	WJS	NEW9 (76.49709 N, 91.29562 W)	47	54
-	WJS	NEW10 (75.62837 N, 85.24802 W)	78	8
-	WJS	ICE	8	n/a
-	WJS	ICE	33	n/a
		WJS TOTALS	**347**	**656**

Table 4. Counts of walruses at terrestrial haulout sites and on ice during surveys of the Baffin Bay (BB) stock during August 2022. Counts on land and ice contributed to total abundance estimates. Sites shaded grey were not surveyed. ID corresponds to Figure 2 haulout locations.

ID	Stock	Haulout Site	Count (Survey 1)	Count (Survey 2)	Count (Survey 3)
54	BB	Littleton Island	-	-	-
55	BB	Coast opposite Littleton Island	-	-	-
56	BB	Uvdle-1	-	-	-
57	BB	Uvdle-2	-	-	-
-	BB	NEW1 (75.65314 N, 78.92382 W)	254	0	0
-	BB	ICE	-	3	-
-	BB	ICE	-	-	6
		BB TOTALS	**254**	**3**	**6**

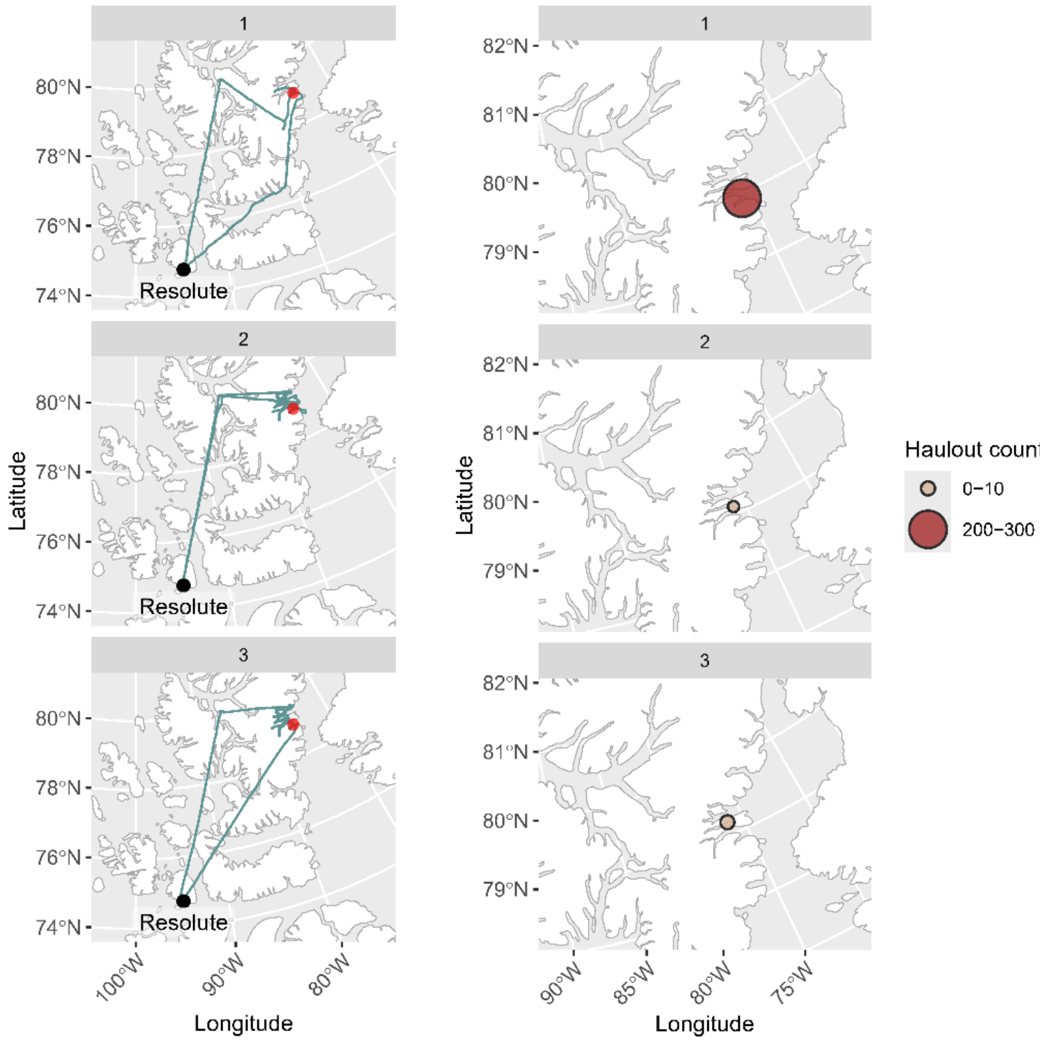

Figure 5. Flight tracks (blue lines) and terrestrial haulouts surveyed (grey points), including one new site (red points), during the first (August 7; top left), second (August 16; middle left), and third (August 26; bottom left) surveys of the Alexandra Fiord complex, the summer core-use area of the Baffin Bay walrus management stock. The right panels indicate raw counts of walrus hauled out on land (top right panel) and ice (middle and bottom right panel) during each survey.

Total counts for the first and second surveys of the PS-LS stock were 266 and 495, respectively, and were 347 and 656 for the WJS stock (Tables 2 and 3). Most walruses were hauled out at terrestrial sites, except for 6 PS-LS and 41 WJS walruses counted on ice (Tables 2 and 3). Total counts for the three surveys of the Alexandra Fiord/Buchanan Bay/Flagler Bay complex (BB stock; Table 4) on August 7, 16, and 26, respectively, were 254 (all on land), 3 (on ice only), and 6 (on ice only). An additional 54, 41, and 46 walruses were observed in water during the three BB stock surveys. Although counts in water did not contribute to abundance estimates, when combined with ice/land counts, they represent the minimum counted population (MCP; see Discussion).

Adjusting counts of walruses hauled out on either land or ice (i.e., ‘dry’) from each survey of each stock resulted in estimates of 887 (95% CI = 475–1,653) and 1,650 (95% CI = 696–3,909) for the PS-LS stock; 1,157 (95% CI = 618–2,166) and 2,187 (95% CI = 1,132–4,224) for the

WJS stock, and 847 (95% CI = 254*–3,286), 10 (95% CI = 3*–44), and 20 (95% CI = 6*–83) for the BB stock (Table 5). Keeping in mind potential walrus movements across stock boundaries (Heide-Jørgensen et al. 2017) and the distance/time cut-off 45 km/day, the first surveys of all three stocks from August 7 (BB) to August 13–16 (PS-LS) and 17–18 (WJS) are considered independent, as are the second and third surveys of the BB stock (August 16 and 26) and the second surveys of the WJS (August 22) and PS-LS stocks (August 24–27). However, walrus could potentially have swum from the BB stock to the WJS and PS-LS stocks (or vice versa) within the period separating the first BB stock survey on August 7 and the second WJS and PS-LS stock surveys toward the end of August (see Discussion).

PBR estimates based on the first surveys of each stock are 6.8 walruses for the PS-LS stock, 8.8 for the WJS stock, and 4.7 for the BB stock.

*Table 5. Walrus abundance estimates ($\widehat{N}$), and associated variance (var($\widehat{N}$)), standard error (SE) and 95% confidence interval (CI) for each survey completed of each management stock (Penny Strait-Lancaster Sound [PS-LS], West Jones Sound [WJS], and Baffin Bay [BB]). * Denotes number of walruses counted, which exceeded the estimated lower 95% confidence limit (CL).*

Stock	Survey	Date	$\widehat{N}$	var($\widehat{N}$)	SE	95% CI
PS-LS	1	August 13-16	887	83,617	289	475–1,653
PS-LS	2	August 24-27	1,650	581,784	763	696–3,909
WJS	1	August 17-18	1,157	144,258	380	618–2,166
WJS	2	August 22	2,187	571,092	756	1,132–4,224
BB	1	August 7	847	440,081	663	254*–3,286
BB	2	August 16	10	78	9	3*–44
BB	3	August 26	20	279	17	6*–83

DISCUSSION

Walruses are challenging to survey due to their clumped distribution and large temporal variation in numbers at haulouts, even over short periods (Mansfield and St Aubin 1991, Lydersen et al. 2008, Stewart et al. 2014a,c). Disturbance by survey aircraft also creates challenges for counting walruses that had been hauled out vs. those that had already been in the water. These challenges are compounded for the High Arctic walrus population, for which telemetry data have demonstrated walrus movements across stock boundaries (Heide-Jørgensen et al. 2017), constraining the period during which they must be surveyed to avoid questions regarding count independence. Despite replicated, nearly complete coverage of the entire summer ranges of the PS-LS and WJS stocks and summer core-use areas of the BB stock, potential movements among stocks and/or incomplete BB stock coverage pose challenges for interpreting the lower BB stock counts with concomitant increases in PS-LS and WJS stock counts during the latter half of August.

* actual count, which exceeds the estimated lower 95% confidence limit (CL).

Placing the 2022 survey results within the context of previous High Arctic walrus stock assessments is difficult because surveys have been conducted in different seasons using different methods (i.e., ship-based vs. aerial), and the entire range of any stock has rarely been covered at once. Survey effort (proportion of known haulouts observed) for the PS-LS and WJS stocks in previous years ranges from 0.21–0.96 and 0.4–1.00, respectively. Among the available time series, total raw counts from surveys that covered at least 90% of the known haulouts surveyed in 2022 were 384, 499, and 540 (in 1999, 2007, and 2009, respectively) for the PS-LS stock, compared to our counts of 266 and 495. Counts comprising at least 90% of known WJS stock haulouts surveyed in 2022 were 110, 176, 374, and 287 (in 1999, 2001, 2008, and 2009), compared to our first and second survey counts of 347 and 656. Comparable counts for the BB stock are limited to the 2009 survey (Stewart et al. 2014a), which flew similar tracks over similar dates as the 2022 surveys. Their raw counts on August 9 and 20 were 135 and 417, respectively, all hauled out on ice (Stewart et al. 2014a), which is comparable to our terrestrial haulout count of 254 on August 7, but higher than our negligible counts of walrus hauled out on ice during the second and third surveys on August 16 and 26. Only an additional 41 and 46 walruses were observed in water on those dates; the resulting MCP of 44 and 52 for each survey cannot account for the unexpectedly low numbers of walrus observed (for comparison, Stewart et al. 2014a observed an additional 72 and 154 walruses in water on August 9 and 20, 2009).

Over the same period, PS-LS and WJS stock counts increased from the first to second surveys. Repeat counts at a number of PS-LS and WJS haulout sites during surveys and opportunistic flyovers throughout August provide a means to assess potential temporal patterns. Of the 14 sites with two to four independent counts, walrus numbers increased throughout August at 10 of the sites. Walruses exhibit considerable temporal variation in haulout proportions. While our variance term captures this variation (Doniol-Valcroze et al. 2016), there is no way, without concurrent telemetry data, to adjust actual point estimates for the appropriate proportion hauled out during the survey, which is unknown and assumed to be 0.3. Point estimates do not differ between the first and second surveys of either the PS-LS and WJS stocks (i.e., they fall within the 95% CI), suggesting count variation can be explained by variation in haulout proportions. Higher counts at 10 of 14 haulout sites are also consistent with coordinated walrus haulout behavior that can be synchronized due to weather and other factors (Salter 1979, Lydersen et al. 2008, Born and Knutsen 1997, Udevitz et al. 2009). However, all surveys were conducted in generally similar conditions.

Another potential explanation is directed movements of walruses transitioning from melting sea ice, their preferred platform when available (Born and Knutsen 1997, Hamilton et al. 2015), to terrestrial haulouts throughout August. While the respective stock ranges are generally ice-free during late summer, 2022 was a late ice year according to local residents, and we noted more ice cover during our first surveys of the PS-LS and WJS stocks relative to the second surveys. Weekly data from the Canadian Ice Service indicate that ice cover in both Penny Strait and Jones Sound decreased from mid to late August (Figure A2), consistent with our observations. Three of the four haulout sites for which walrus counts decreased between surveys were the new sites observed on southeast Bathurst Island/western Queens Channel on August 13, when these sites together numbered 180 walruses (sites NEW3-6, Table 2, Figure A1). During the second survey on August 22, these sites had 0 walruses, while the count at the traditional Borgen Mount haulout site to the northeast increased from 0 to 222 from the first to second survey, suggesting walruses may have followed receding sea ice into the area during the interim period. Again, without concurrent telemetry data, the possibility that walruses moved from melting sea ice onto terrestrial sites cannot be evaluated.

Another (not mutually exclusive) hypothesis to explain higher PS-LS and WJS counts coincident with lower BB stock counts is an influx of walruses from the BB to the PS-LS and WJS stocks. Our main goal had been to survey all three walrus stocks over a sufficiently short period to avoid bias due to walrus movements among stocks, in particular directional movements from Smith Sound/coastal Ellesmere Island into Jones Sound and Lancaster Sound, as demonstrated by Heide-Jørgensen et al. (2017). The Alexandra Fiord/Buchanan Bay/Flagler Bay complex is ~ 600 km from observed walrus haulouts in western Jones Sound and ~ 1,000 km from haulouts in Penny Strait where walruses were observed (Figure 4). The distance-time criterion of 45 km/day used to assess independence of haulout counts was determined for a different walrus stock crossing Davis Strait from Greenland to southeast Baffin Island (Dietz et al. 2014). However, Heide-Jørgensen et al. (2017) reported similar swim speeds for walruses crossing Smith Sound, which traveled an average speed of 1.9 km/hr, or approximately 46 km/day. Travelling at similar speeds, walrus likely could not have covered the ~600 km from Alexandra Fiord to western Jones Sound in the 10 days separating the August 7 and August 17-18 surveys, while covering the ~1,000 km to Penny Strait in the six days between August 7 and the first PS-LS stock survey (August 13-16) is even more unlikely. However, walruses could have covered the distance from Alexandra Fiord to WJS during the 15 days separating the August 7 and August 22 surveys, and even the larger distance to the PS-LS stock could have been covered in the 20 days leading up to the second survey that ended on August 27.

It is not known whether walruses from the BB stock regularly move into Jones Sound and Lancaster Sound, or to what extent. Heide-Jørgensen et al. (2017) observed 12 of 50 tagged walruses undertook such movements in 2015, although none of the (admittedly much smaller number) four walruses tagged in previous years did so. Heide-Jørgensen et al. (2017) suggested sea ice availability may influence walrus movements from Smith Sound into Jones and Lancaster Sounds. However, 2022 was, by local accounts, a heavy ice year, and there was plenty of drifting pack ice present in Smith Sound during all three surveys. Moreover, while the proportion of tagged animals observed by Heide-Jørgensen et al. (2017) to have moved from BB into WJS and PS-LS stocks (0.24) was not negligible, a much larger proportion (~ 0.83-0.85) of the entire stock would have to have undertaken such movements to account for the difference in counts during the first (254 on land + 54 in water) vs. second (3 on ice + 41 in water) and third (6 on ice + 46 in water) BB stock surveys.

The exclusion of Ellesmere Island coastline to the south and north of the surveyed area introduces an unknown degree of negative bias in our BB stock counts, and could potentially account for the differences between the first vs. second/third surveys. Although excluded areas south of the Alexandra Fiord/Buchanan Bay/Flagler Bay complex had no or few walruses during surveys in 1999 and 2008 (Stewart et al. 2014a), walruses do occur farther south along the Ellesmere coast to Jones Sound (Born et al. 1995, Stewart et al. 2014a). Heide-Jørgensen et al. (2017) found Talbot Inlet/Goding Bay was the second most frequently visited area along Ellesmere Island by walruses during summer in 2015. Small numbers of walruses were also sighted farther north in Archer Fiord in 2018 (Yurkowski et al. 2019), which was included in survey plans but dropped due to fuel shortages. Our exclusion of abandoned haulouts on the Greenland side of Smith Sound may have also introduced negative bias in our BB stock counts. Although the August survey period is after walruses migrate to summering areas along Ellesmere Island by early July, and well before they return during October (Heide-Jørgensen et al 2017), a 'sizeable group' of walrus was observed hauled out on Cape Sherard, Greenland in early August 2008 (Stewart et al. 2014a), suggesting they may have begun to reoccupy historic haulouts there. Finally, flight paths within the Alexandra Fiord/Buchanan Bay/Flagler Bay complex did not cover the entire area systematically. While visibility to both coasts of any given fiord surveyed was generally good, it is possible that walruses hauled out on ice were missed, despite their stark color contrast. Without concurrent telemetry data, it is not possible to evaluate hypotheses about how movements beyond or within stock boundaries may have influenced counts across different surveys.

Prior to proposals to subdivide the High Arctic walrus population into its current three management stocks (NAMMCO 2006, NAMMCO 2011, Stewart 2008), the population was considered one putative stock called the North Water (Baffin Bay-Eastern Canadian Arctic) stock (Born et al. 1995, NAMMCO 2006). Heide-Jørgensen et al. (2017) proposed that the High Arctic walrus population be managed as a single shared stock between Canada and Greenland based on movements of walrus across purported stock boundaries, and Greenland continues to manage the population as a single stock (Wiig et al. 2014). Microsatellite DNA differences support the separation of the WJS stock, but exhibit little differentiation between the PS-LS and BB stocks (Shafer et al. 2014). Combining the first surveys of all three stocks produces a population abundance estimate of 2,891. The second PS-LS and WJS surveys can be similarly combined with either the second or third BB survey (either of which would satisfy the distance/time criterion), producing a second estimate of 3,847 or 3,857, respectively.

Despite uncertainties in stock structure, spatial structure within the High Arctic walrus population (e.g., Stewart 2008) introduces potentially unequal harvest pressure on walruses in different areas. In that case, stock-based abundance and associated PBR estimates are most conservative for avoiding negative management outcomes such as local depletion. High Arctic walruses are hunted primarily in Jones Sound (Canada) and the Greenland side of the North Water polynya. Stewart (2008) contends most of the walruses hunted annually in Grise Fiord may be from the BB stock, since WJS walruses remain within the western end of the sound while hunts take place primarily from Grise Fiord eastward towards Coburg Island (Priest and Usher 2004). The Nunavut communities of Pond Inlet, Arctic Bay, and Resolute Bay presumably hunt from the PS-LS stock (although some Pond Inlet hunters boat into the North Water and likely hunt from the BB stock). Landed hunt data (1997-2022) in Canada (Table 6) are generally below PBR estimates for the PS-LS and WJS stocks. We note, however, that hunt data is negatively biased due to non-reporting, and the struck and lost rate, which is generally assumed to range from 30-38% (Stewart et al. 2014b), is unknown and not incorporated in Table 6. However, annual hunts from the BB stock from 2018-2022 approach or exceed PBR estimates, particularly if Grise Fiord counts are considered. Adding the 79 walruses hunted in Greenland from the BB stock during winter (NAMMCO 2018) exceeds individual BB stock PBR estimates, and is therefore cause for concern (even if considering the take potentially draws from all three stocks, as suggested by the telemetry results of Heide-Jørgensen et al. [2017], 79 walruses also exceeds the combined PBR). PBR calculations are sensitive to the value of F_R, whose assignment from a range of 0.1 to 1 depends largely on stock size and trend (DFO 2025). Infrequent assessments introduced uncertainty in our understanding of current trends for all three High Arctic walrus stocks, which was reflected in the selection of a lower, more conservative F_R of 0.25 (DFO 2025). More frequent surveys would allow for assessment of stock trend (i.e., increasing, stable, or decreasing) and associated F_R, and ultimately the use of population models to estimate stock demographic parameters and trend (Hammill et al. 2016 a,b).

Finally, from a survey protocol perspective, the 55 mm lens provided clearer and closer images of walruses while still easily encompassing entire haulout sites. We recommend it be used in future walrus surveys to allow for counting calves, which will be important for implementing an Ecosystem Approach to Fisheries Management and eventual parameterization of age-structured population models. Using 55 mm lenses might also allow the survey aircraft to fly higher, potentially reducing the number of walruses disturbed.

Table 6. Annual numbers of walrus hunted for by Nunavut communities from High Arctic walrus stocks from 1997/1998 to 2021/2022 (reported and compiled for fiscal year, which runs from April to March). The table below attributes all Grise Fiord hunts to either the West Jones Sound or Baffin Bay stocks, while Resolute Bay, Arctic Bay, and Pond Inlet are all considered to take from the Penny Strait-Lancaster Sound stock (see Discussion). No sport hunts have been reported by these communities for the 25-year period (NR = Not Reported).

	West Jones Sound (WJS) Baffin Bay (BB)	**Penny Strait-Lancaster Sound (PS-LS)**			
Year	**Grise Fiord**	**Resolute Bay**	**Arctic Bay**	**Pond Inlet**	**TOTAL**
1997/98	**12**	0	0	0	**0**
1998/99	**11**	NR	3	0	**3**
1999/00	**5**	1	1	1	**3**
2000/01	**4**	0	2	5	**7**
2001/02	**2**	NR	2	3	**5**
2002/03	**3**	1	0	0	**1**
2003/04	**7**	6	0	1	**7**
2004/05	**5**	4	1	0	**5**
2005/06	**2**	1	NR	1	**2**
2006/07	**5**	0	0	0	**0**
2007/08	**4**	1	1	0	**2**
2008/09	**NR**	NR	NR	NR	**NR**
2009/10	**7**	2	0	NR	**2**
2010/11	**2**	3	1	3	**7**
2011/12	**4**	2	0	0	**2**
2012/13	**NR**	2	0	NR	**2**
2013/14	**0**	0	0	0	**0**
2014/15	**16**	1	0	0	**1**
2015/16	**1**	0	0	1	**1**
2016/17	**0**	0	0	1	**1**
2017/18	**NR**	0	2	10	**12**
2018/19	**5**	0	NR	1	**1**
2019/20	**4**	0	NR	0	**0**
2020/21	**0**	2	1	0	**3**
2021/22	**5**	4	NR	NR	**4**

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APPENDIX

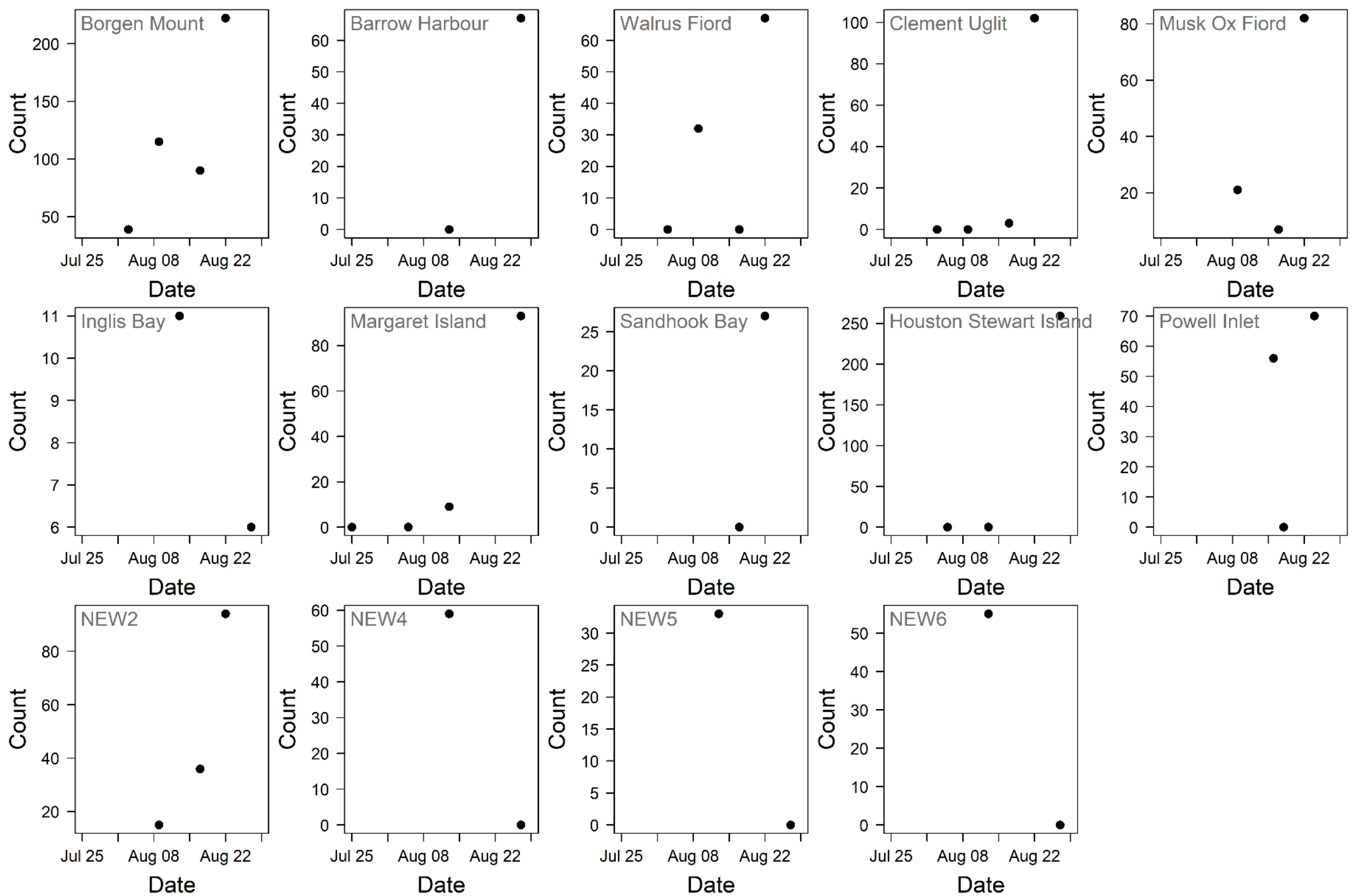

Figure A1. Fourteen terrestrial haulout sites with two or more counts during the survey period. Counts were higher towards the end of August for 10 of the 14 sites.

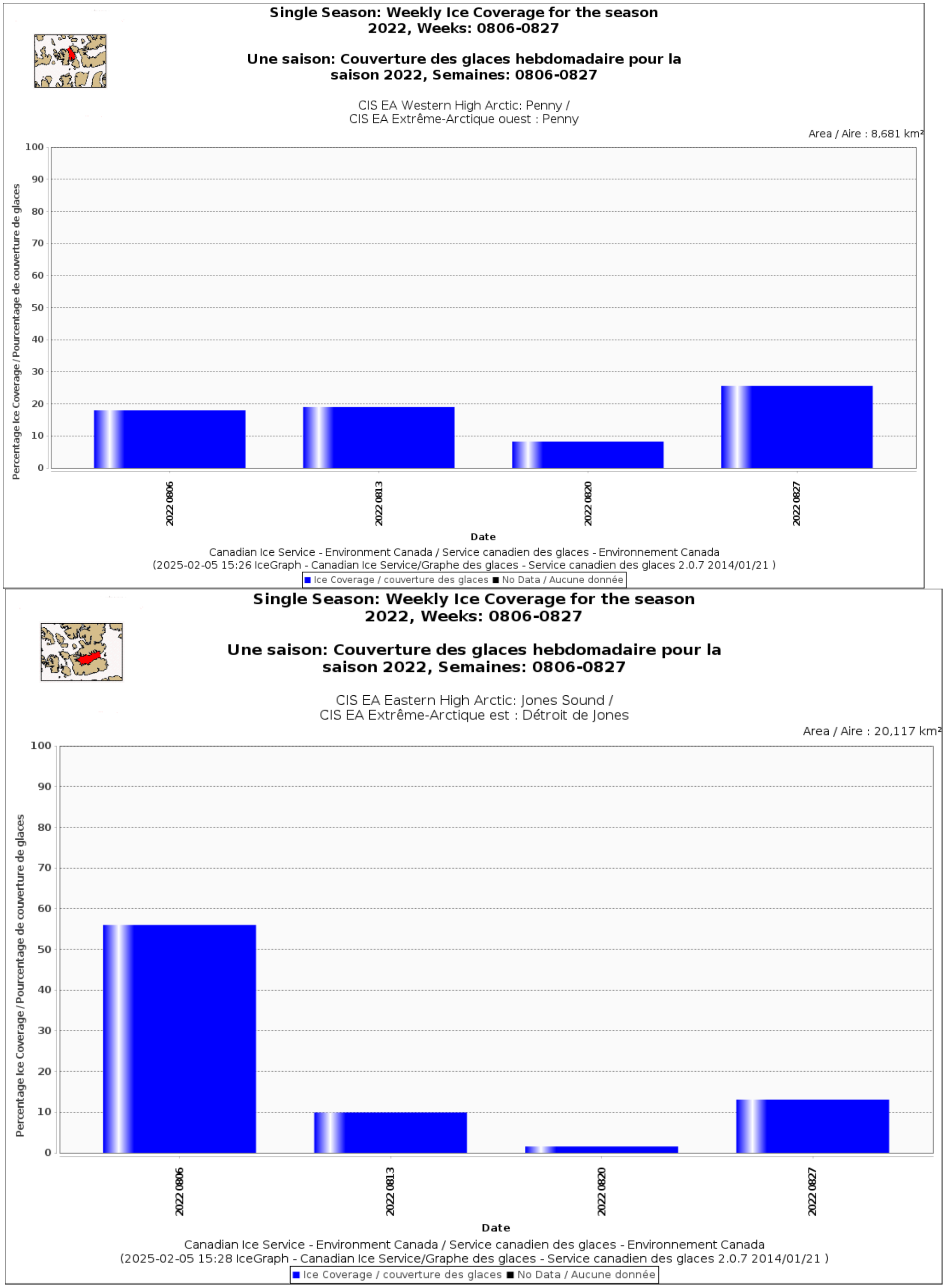

Figure A2. Weekly percentage ice cover of Penny Strait (top) and Jones Sound (bottom) throughout August 2022. Both areas had drops in ice cover from the second to third weeks of August, which corresponded to the first and second surveys of the Penny Strait-Lancaster Sound (PS-LS) and West Jones Sound (WJS) walrus stocks (Government of Canada 2025).